

Cooperation and conflict resolution in groundwater and aquifer management

W. Todd Jarvis

Institute for Water & Watersheds and College of Earth, Ocean and Atmospheric Sciences,
Oregon State University, Corvallis, OR, USA todd.jarvis@oregonstate.edu

1 INTRODUCTION

Conflicts over water depend on the characteristics of the resource. Conflicts over groundwater and aquifers are very different from those posed by surface water resources. Surface water negotiations typically focus on allocations and flows; negotiations over groundwater typically focus on storage and water quality. Whereas surface watersheds, the common boundary for integrated water resource management, are static, groundwater boundaries are value laden and constantly change during development. The resources are often times managed separately even though both resources are hydraulically connected.

Formal groundwater hydrology differs dramatically from popular groundwater hydrology. Conflicting conceptual models are commonplace for both permeability architecture and groundwater circulation. Dueling experts can easily overtake conflicts focusing on identity, interests, and the investments and risks connected to groundwater and aquifers.

Science remains at the core of groundwater and aquifer disputes. Disagreements over groundwater science and engineering are not easily defined without the assistance of experts trained that also exercise skills in process. Cooperation on groundwater and aquifer governance takes many forms by first dealing with the dueling experts situation through scientific mediation. Learning and experiencing different water negotiation frameworks through serious gaming enhances participatory approaches to adapting existing subsurface governance.

2 TRIGGERS OF CONFLICT

A contentious groundwater situation can be classified as a wicked problem, employing features of complexity - it is unpredictable, uncontrollable, and it has several, often contradictory interpretations (Kurki, 2016). The perception that conflicts or negotiations over groundwater and aquifers are all about allocation and ownership is misinformed. Some of the most contentious

ADVANCES IN GROUNDWATER GOVERNANCE (book title)

Karen G. Villholth, Jac van der Gun, Elena Lopez-Gunn, Kirstin Conti, and Alberto Garrido (editors) –
In progress, please do not cite (yet)

battles over groundwater focus on the perceived threats to the quality of groundwater. There also exists a “hydrohydra” – a many-headed beast – of myths, paradoxes and misunderstandings of the tenets within hydrogeology that ultimately leads to conflicts between groundwater professionals as well as a lack of trust by decision makers (Jarvis, 2014 – see Figure 1).



Figure 1: Groundwater Issues Map (Jarvis, 2014).

Looking beyond the internal conflicts within the field of hydrogeology, Delli Priscoli & Wolf (2009) indicate the interpersonal causes of conflict that may overwhelm the hydrogeologic confusion include:

- Relationships (poor communication, negative behavior)
- Data (interpretation, misinformation, procedures)
- Interests (perceived competition, procedural interests)
- Structural (unequal power in terms of bargaining, material and ideational power, time, destructive behavior, geography)
- Values (ideology, spirituality)

Jarvis (2014) added “identity” as a basis for conflict that is especially unique to groundwater and aquifers. Identity in this context includes history and control, as well as the “dueling experts” common in “formal” hydrology and folk beliefs (e.g., dowsing or water divination) common in “popular” hydrology. Conflicting conceptual models are part of the formal training of

ADVANCES IN GROUNDWATER GOVERNANCE (book title)

Karen G. Villholth, Jac van der Gun, Elena Lopez-Gunn, Kirstin Conti, and Alberto Garrido (editors) –
In progress, please do not cite (yet)

hydrogeologists focusing on the intellectual method of “multiple working hypotheses” introduced in the late 1890s by the first hydrogeologist in the US, Thomas Chamberlain. The structure of the method of multiple working hypotheses revolves around the development of several hypotheses to explain the phenomena under study. The antithesis of multiple ways of knowing is considered a “ruling theory, often espoused by “local heroes” or individuals who consider the geology and hydrology of where they live and work as so complex and unique that only a “local” professional would understand how “their” hydrogeology “works” (Jarvis, 2014). As a consequence, conventional groundwater management approaches, drawing from expert-based instrumental rationality, often are insufficient for successful project planning and implementation (Kurki, 2016).

At local scales, conflicts over groundwater and aquifers may arise between parties because of the land–water nexus and the large investments required to purchase and develop the land, while trying to weigh the value of maintaining a quality of life through open space initiatives and preserving the local water quality (Jarvis, 2014; Kurki, 2016). Conflicts in these settings also arise due to the plethora of “popular” beliefs of how groundwater is stored, or how groundwater masquerades as surface water in cases of groundwater flooding.

Resolving groundwater conflicts can be particularly tricky due to many other factors including a lack of aquifer performance data, spotty water quality data, traditional and preferred easy access to water, the extensive variety of draws on a single aquifer, historical water rights in conflict with the needs of new population and economic growth, exemptions for domestic wells, the “right to life,” and the list goes on (Vinett & Jarvis, 2012). Superimposed on all of these drivers of conflict is the administrative separation of laws governing groundwater, surface water, and seawater, suggesting the physical, biological, and political boundaries between the groundwater, surface water, and seawater are easily delineated.

3 GROUNDWATER BOUNDARY CONUNDRUM

Defining boundaries around groundwater resource domains is conflictive because boundaries represent different interpretations of key issues, such as water quality, water quantity, nature, economics, politics, and history. Boundaries define who is in, who is out; what is permissible, what is not; what needs to be protected and what is already protected (Jarvis, 2014).

ADVANCES IN GROUNDWATER GOVERNANCE (book title)

Karen G. Villholth, Jac van der Gun, Elena Lopez-Gunn, Kirstin Conti, and Alberto Garrido (editors) –
In progress, please do not cite (yet)

Some might argue that defining boundaries around a hidden resource is “fuzzy” and perhaps impossible to do with any degree of certainty. However, the literature is replete with boundaries for groundwater domains. Careful examination of the literature reveals three groundwater domains: (1) traditional approaches to defining groundwater domains that focus on predevelopment conditions – the commons; (2) groundwater development creates new boundaries, that meshes hydrology, hydraulics, property rights and economics – the hydrocommons; and (3) the social and cultural values of the groundwater and aquifer resources create boundaries to define the “commons heritage”.

The typology shown in Figure 2 continues to grow with time as technology permits increased use of groundwater and aquifers. Groundwater and aquifer boundaries will have to focus more on the notions of “problemsheds” and “policysheds” – the boundaries of a particular problem or policy defined by the groundwater and aquifer users (Jarvis, 2014). For example, Aladjem (2015) identified the “sleeper” issue that needs to be addressed while implementing the California Sustainable Groundwater Management Act of 2014 is the question of defining the boundaries of the groundwater basins.

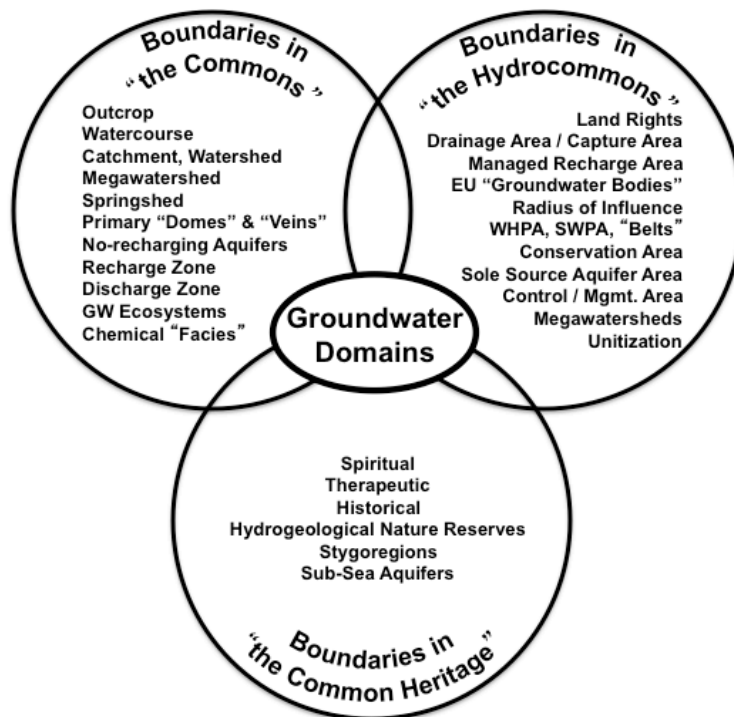


Figure 2: Groundwater Boundary Topology (Modified from Jarvis, 2014).

4 GEOGRAPHY OF CONVENTIONAL GROUNDWATER CONFLICTS

While a comprehensive geographic inventory of groundwater conflicts is beyond the scope of this chapter, the following vignettes are used to illustrate some of the types and responses to groundwater conflicts.

4.1 Groundwater for Agriculture

It is well known that groundwater represents a large share of water used for agriculture irrigation (OECD, 2015). Ease of “point of use” and “water on demand” is a key driver to global groundwater use.

California serves as a good example of the tension associated with agricultural use of groundwater given the importance of the state for providing a significant share of the US food supply. Groundwater provides about 40 to 60 percent of all water used in California. The Earth Security Group (2016) identified the situation in California as a global aquifer hotspot.

Groundwater in California went unregulated until passage of the Sustainable Groundwater Management Act (SGMA) in 2014 (Aladjem, 2015; Moran *et al.*, 2016). Prior to the SGMA, water rights were acquired through an adjudication process that was largely driven by the goal of attaining “safe yield”. Recalling that safe yield is part of the “hydrohydra” of issues facing hydrogeologists, safe yield of a basin as defined by existing California case law was not the same as the “sustainability yield” of basin outlined in the SGMA (Aladjem, 2015).

Beyond the boundary issues and confusion over “safe yield” versus “sustainability yield”, other factors contributing to conflict over groundwater in California identified by (Moran & Cravens, 2015) that probably sound familiar to practitioners in water conflicts across the globe include:

- Fragmented Groundwater Management
- Voluntary Groundwater Management
- Legal Uncertainty in the SGMA
- Property Rights and Existing Legal Rights to Water
- Data, Information, Models, and Dissemination of Data
- Funding and Support

4.2 Groundwater for Growth

The fragmented nature of water and land use laws at the level of individual states and provinces is leading to a new paradigm in water planning and management that focuses on a “bottom-up” approach instead of the traditional “top-down” approach. Concurrency laws for proposed land use have evolved over the past 15 years to address groundwater recoverability and aquifer mechanics. Jurisdictions across are crafting policies that specifically require “proving” water availability for housing developments (California, Colorado, Texas, Utah) and new agricultural uses (California). Some counties are also weighing interference between proposed developments and senior surface water rights through uncontrolled pumping of groundwater through domestic wells (Washington). Elsewhere, counties are asked by state governments to develop groundwater management plans to ascertain the availability to other high value uses such as permitting short term sales of groundwater with appropriated for agricultural uses to the drilling industry for hydrofracking (Wyoming).

Implementation of concurrency ordinances, as well as groundwater sustainability initiatives such as California’s SGMA, require making decisions in the face of uncertain data. Funding shortfalls, the uncertainty associated with the quantitative characteristics of groundwater systems, increased use of numeric groundwater models as necessary components for informed groundwater management decisions, yield a growing frustration with the “dueling expert” situation (Jarvis, 2014).

4.3 Groundwater for Ecosystems

Conflicting conceptual models connected to how groundwater is “valued” are best exemplified by the situation where the Santa Cruz Aquifer is shared between the US and Mexico. Communities in Mexican state of Sonora and the US state of Arizona are heavily reliant on groundwater for agricultural, municipal, and industrial uses. The Santa Cruz Aquifer is not the subject of any treaties (Delgado, 2013).

Water agencies in both countries operate independently with little coordination regarding the data collection and conceptual models of the aquifer. The obvious results of such fragmented

coordination are different interpretations of water availability, impacts of groundwater use, recharge and protection activities. For example, the Arizona Department of Water Resources (ADWR) established five Active Management Areas (AMA). An AMA establishes management rules for aquifer use including permitting, monitoring, restrictions on new irrigation and development, as well as annual use and reporting. For the Santa Cruz AMA, the goal is to maintain “safe yield”, preserve the riparian areas, and prevent a decrease in the water table. In contrast, the goals of the state of Sonora focus more on the general well being of the population, including the development of basic water services, as well as extension and improvement of the existing groundwater-based supplies. The aquifer “use” by each country yielded conflicting hydrological conceptual models that have led to disagreements of the physical conditions and availability of groundwater. While open dialogue has yielded a modicum of cooperation on some scientific information, there is still no agreement on a collaborative assessment or management of the Santa Cruz Aquifer (Delgado, 2013).

5 GEOGRAPHY OF EMERGING GROUNDWATER CONFLICTS

5.1 Nitrate Wars

Excess nitrate concentrations in aquatic systems, in combination with other nutrients such as phosphorus, lead to algae blooms in ponds, lakes, streams and rivers. Large algae blooms also contribute to hypoxia, or low dissolved oxygen, in lakes and rivers that negatively impacts many fish species. The World Health Organization drinking water standard for nitrate is 10 milligrams per liter to prevent nitrate toxicity.

Agricultural fertilizer use, onsite wastewater systems (septic tanks) and animal wastes are typically associated with rural residents. Urban dwellers many times rely on drinking water supplies that are transmitted long distances to the point of use. Rural dwellings are sometimes located upstream from urban areas where rivers and lakes are valued for water amenities and fisheries; sometimes rural residential developments are located in aquifer recharge areas thus creating tension between urban and rural communities.

Community cohesion and civility becomes fragmented and deepens the urban-rural divide when it comes to the issue of delineating protection areas for wellheads, springs, and recharge areas for

public drinking water supplies. There is also the perception that onsite wastewater systems contaminate of groundwater and surface water, thus impacting the water quality of rivers and streams, as well as the drinking water supplies, utilized by urban areas (Jarvis, 2014). The antagonism between urban residents who feel an affinity to the “greater good” versus rural residents who value independence and wide open spaces and who “just want to be left alone” is real. These types of conflicts are becoming more commonplace with exurban development. Conflicts over nitrate and the urban-rural divide can last decades. A good case study of a nitrate war across the urban-rural divide in Wyoming continues after over 20 years of dueling experts and a general lack of appreciation for the role of a neutral third party with skills in both process and substance is summarized by Jarvis (2014). Kurki (2016) provides a case study of a comparable urban-rural divide situation where tensions continue to flare in Finland as described in a later section.

5.2 Groundwater Flooding

Neighbor wars come in many shapes and sizes. “Border disputes” range from barking dogs, noisy neighbors, nosy neighbors, fencing or lack thereof, fugitive trees and vegetation, neighborhood blight, “attractive nuisances” such as pools, private lakes, wildlife, episodic stormwater runoff, and increasingly, groundwater flooding. Groundwater flooding is an emerging problem globally with changes in land use (deforestation, impervious surfaces) and changes in precipitation patterns (more rain, less snow). Groundwater flooding is a frequent problem in areas where the depth to groundwater is shallow. It is common in rainy climates and urban areas such as the United Kingdom. Yet the situation is increasingly “in the news” in both urban and rural areas that receive moderate precipitation such as Rocky Mountain and Midwest states of the US, arid regions in the Middle East, and rainy, deforested regions in the Pacific Northwest.

Stormwater flooding oftentimes is controlled through “engineered” structures such as culverts, gabions, and ditches that direct flow to creeks and rivers. Stormwater situations become unfriendly once the engineered features direct flow to a neighbor resulting in damaged property. Groundwater flooding is a stealth variety of stormwater flooding. Groundwater flooding is perceived as stormwater that is controllable by collection, diversion, and discharge. Yet the control of groundwater flooding through traditional approaches is a mirage. The problem is a “supercharging” of shallow aquifers, filling shallow aquifers “over the brim” yielding full ditches

and small ponds. Digging ditches deeper to increase drainage only permits more groundwater to flow into the excavations. Efforts to drain one property owner's lands through drainage ditches only exacerbate the collection of "stormwater" on their neighbor's land.

The conflicts resulting from the perceived solutions to fugitive water drainage often leads to long-term conflict over the episodic efforts to drain supersaturated land. Only through extensive outreach to stakeholders by a groundwater professional steeped in process skills using participatory approaches to engineering design over a period of two years yielded increased trust between "nuisance water neighbors" (Kemper, 2016).

5.3 Managed Recharge

Managed aquifer recharge (MAR) is increasingly used to combat water scarcity. Large MAR projects exist in the Middle East, Australia, Europe, Jamaica, and across the US. Given that MAR is considered a solution to a water scarcity problem, it is surprising to learn of how conflictual the practice is in some locations in the world.

Finland has abundant water resources, yet community water supplies are increasingly reliant on mixtures of natural and artificially recharged water to improve water quality for municipal and industrial uses. However, potential areas for groundwater development and supplemental MAR are sparsely situated (Kurki, 2016). Urban areas many times convey developed groundwater long distances from rural areas. Like the Nitrate Wars, tensions across the urban-rural divide create long-term conflicts, often times leading to extended litigation. Kurki (2016) indicates "history matters" when it comes to assessing conflicts over groundwater and alternative uses of aquifers, as well as anticipating conflicts, through stakeholder analyses.

5.4 Subsea Aquifers

The interaction between seawater and terrestrial groundwater is garnering much attention with sea level rise and ocean pollution. Perhaps the most relevant to the challenge of groundwater governance is the recognition of fresh and brackish groundwater reserves stored below the sea floor. The potential volume of fresh and brackish water stored in offshore aquifers may be two

ADVANCES IN GROUNDWATER GOVERNANCE (book title)

Karen G. Villholth, Jac van der Gun, Elena Lopez-Gunn, Kirstin Conti, and Alberto Garrido (editors) –
In progress, please do not cite (yet)

orders of magnitude greater than the approximately 4,500 km³ estimated to have been extracted globally from continental aquifers since 1900 (Post *et al.*, 2013).

This is an important discovery that begs the question as to how the subsea aquifers will be governed - as part of the global commons, through the Law of the Sea, a Law of the Hidden Sea, or through some form of contract or operating agreement? Martin-Nagle (2015) argues that even if the challenges regarding accessibility and financial return can be negotiated, jurisdictional issues and ownership of the water needs to explore how domestic law, international water law, or the Law of the Sea fit into the puzzle. “Aquifers lying under the territorial sea of one nation would doubtless be governed by its domestic laws, but questions would arise for transboundary aquifers. If international water law principles were to guide ownership and use, a further determination would have to be made about which guidelines to follow. Rather than ownership of water following national boundaries and territorial seas, a new regime might be constructed whereby the reserves would be viewed as a common asset belonging to all peoples.” (Martin-Nagle, 2015).

There are other instruments used to manage subsurface reservoirs (or aquifers) such as oil, gas, geothermal, carbon sequestration, and hydrofracking using the “regime” of unitization. Unitization is the well-known collective action approach of managing oil or gas reservoirs by all the owners of rights in the separate tracts overlying the reservoirs that has been in practice for over 100 years (Jarvis, 2014). “Pooling” is sometimes referred to as unitization. Unitization as employed in the oil industry is designed to be collectively beneficial, and is practiced in 38 states, in 13 countries, and most recently is the proposed approach for sharing transboundary hydrocarbon resources in the Gulf of Mexico as outlined in the US-Mexico Transboundary Hydrocarbons Agreement of 2012. Clearly, boundaries of the groundwater bodies including legal, political, hydrological, geological, biological, financial, and technical, will be an important facet of developing this “new” groundwater resource. However, unitization could serve as the ideal approach for governing subsea aquifers, as well as both developed and undeveloped terrestrial aquifers, given that unitization was initially designed for dispute prevention as opposed to conflict resolution.

5.6 Hydrofracking

The media “hydrohysteria” regarding the threat of hydrofracking to local, regional, and national water supplies has brought the general public to the fore regarding conflicts over groundwater quantity and quality. Documentary film is increasingly serving as a medium for discourse in the hydrofracking situation. Consider, for example, the documentary *Gasland* that portrays the global efforts of hydraulic fracturing for natural gas in unconventional shale reservoirs as contaminating groundwater and impacting private wells. *FrackNation* counters many of the assertions in *Gasland*. *Gasland, Part II* was filmed to counter *FrackNation*.

The hydrofracking debate spans all scales of conflict spanning from “micro” with some communities voting to ban fracking, to the “meso” with counties, states, and provinces passing legislation to prohibit fracking or even related industries (e.g., “frac” sand mining) from operating within their boundaries. A few nations, such as France and Bulgaria, represent the “meso” scale for banning hydrofracking.

The conflicts over hydrofracking are so wicked that the situation is best viewed through the lens of systems thinking depicted on Figure 3. Systems thinking serves as the best method of analyzing the hydrofracking controversy because it (1) promotes a holistic understanding that is both accessible and pluralistic, (2) transforms a single issue focus into a multi-issue view, (3) clearly illustrates that complex situations cannot be fully managed/controlled, (4) corresponds well to natural resource management, (5) encourages agencies to think beyond their default formulation of the situation paradigms that have emerged in the past 25 years (Daniels & Walker, 2012).

Fracking bans are evolving out of fear over “direct” versus “indirect” impact to air quality, land quality, surface water quality, groundwater, and earthquakes associated with both the fracking process and injection of the produced waters. The interface between the different natural media and humans best classifies these conflicts as an interest-based Coupled Human-Nature Complex (Figure 3).

The investments and associated risks with fracking create a form of Regulatory-Industrial Complex. Tension between industry and regulatory agencies many times lead to lags in

regulatory frameworks. Conflicts within the industrial domain are manifold, ranging from multiple working hypotheses associated with conceptual geologic models that dictate some of the fracking technology. The regulatory domain juggles conflicts with water use, familiarity with conventional fracking technologies common in vertical wells to the new unconventional fracking approaches associated with horizontal wells.

Well drillers and drilling engineers take great pride in their work and take umbrage when wells of all varieties are targeted as part of the hydrohysteria associated with hydrofracking. A form of a Socio-Technical Complex creates an identity-based conflict because the drilling industry values a shared emphasis on their achievement of both excellence in technical performance and quality in their work.

Clearly, no single approach to conflict resolution or water negotiations framework can be implemented to the “wicked” local, regional, national, or international hydrofracking situation. The value of transdisciplinarity continues to be acknowledged as key to groundwater conflict resolution, groundwater negotiations, and groundwater governance; however, limited guidance is available on achieving it in practice.

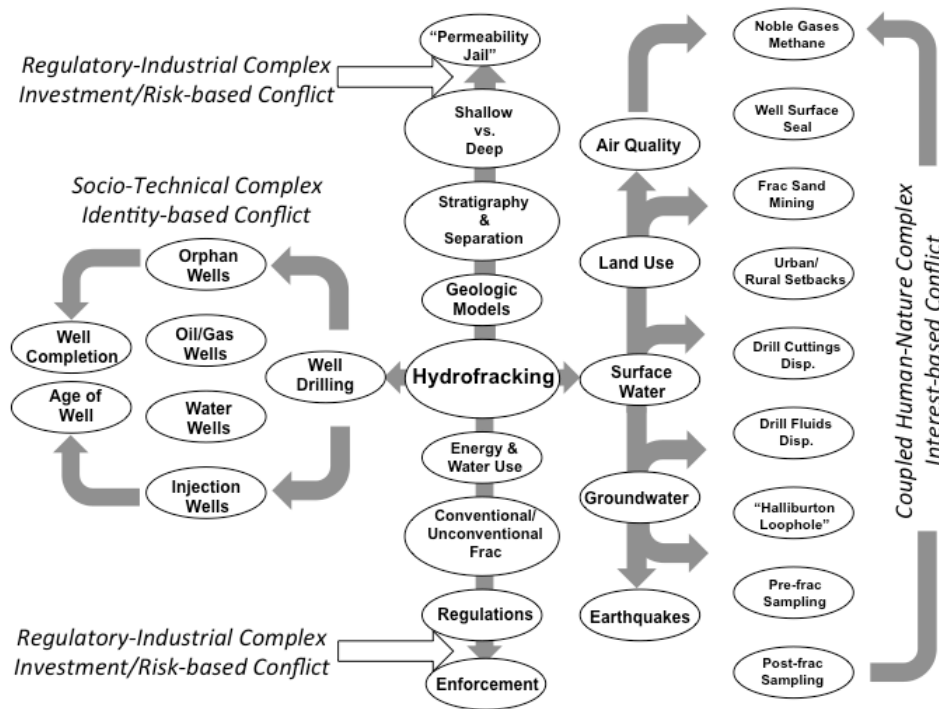


Figure 3: Hydrofracking Situation Map.

6 PATHS FORWARD FOR COOPERATION

6.1 Water Negotiation Frameworks

What are the best approaches to negotiations over water? The answer to this question mimics the problem of defining the vague concepts of safe yield and sustainability discussed in earlier sections – the best approach depends on whom you ask and when you ask. Water negotiation frameworks come in many names and forms. The following is a brief summary of a few water negotiation frameworks described in the literature and comparing them to negotiative approaches.

- Four Worlds Framework – This identity-based framework was developed by Aaron Wolf as part of the Program in Water Conflict Management and Transformation at Oregon State University and is described more fully by Jarvis & Wolf (2010). This water conflict transformation approach points disputants towards topics of issues of rights, needs, benefits and equity, while at the same time attempting to move beyond institutions towards creating incentives in the quest to create a new superordinate identity where the parties realize “we are all in this together”. The negotiative approaches in this framework include (1) reasoned persuasion and games of reason, (2) relational negotiation, and (3) “I feel your pain” games discussed by Benjamin (2015).
- Water Diplomacy Framework – This interest-based framework was developed by Islam & Susskind (2013) as part of the Water Diplomacy training at Tufts University. This framework sets its sights on the flexible uses of water and joint fact finding to create value, rather than zero-sum thinking through a loop of societal, political and natural networks. The negotiative approaches in this framework include (1) reasoned persuasion and games of reason, (2) the “caucus-style” negotiation, and (3) the “divide and conquer” games discussed by Benjamin (2015).
- The Water Security Framework – This investment/risk-based framework was developed by Mark Zeitoun as part of the Water Security for Policy Makers and Practitioners training at the University of East Anglia. This framework utilizes a web of climate, energy, food, water and community to define what might be tolerable risk for water use and reuse without getting into “trouble”. The negotiative approaches in this framework include (1) positional bargaining and the “high-low” game, (2) “caucus-style”

- negotiation, (3) the “divide and conquer” game, and (4) the competitive negotiation and the intimidation games discussed by Benjamin (2015).
- Hydro-Trifecta Framework – This framework acknowledges there is not one framework that works better than the others, but rather integrates all of referenced frameworks into a transdisciplinary-based approach (Jarvis, 2014). This framework acknowledges the scalability of negotiations, along with systems thinking as described by Daniels & Walker (2012), all of which are important to collaborative learning, building competencies or acquiring new skills, to invent new science. The hydrofracking situation is an excellent example of how systems thinking and integrative negotiative approaches are key to just about any wicked problem. All of the negotiative approaches described by Benjamin (2015) are part and parcel of this framework; however, the “caucus-style” negotiation and the “divide and conquer” games are emphasized given the recognition that online negotiations and shuttle diplomacy are increasingly used in multi-dimensional, multi-media situations given advances in communication technology.

6.2 Scientific Mediation

“Scientific mediators attempt to tread the path between “Merchants of Doom” and “Merchants of Doubt” as “Merchants of Discourse” using multiple working hypotheses and multiple ways of knowing as their moral compass” (Moore *et al.*, 2015). While at first glance it appears silly that water professionals cannot get along, but first hand experience by Moore *et al.* (2015) revealed that water scientists and engineers are like other people with personal and professional opinions that can affect their work. Likewise, groundwater professionals have a strong personal affinity to their work given that “imagination” is a key part of developing their working hypotheses. The ownership of the creativity associated with imagining what is going on in the subsurface can lead to a “dueling experts” situation. The danger of not addressing a dueling expert situation in an effective manner leads to distrust in groundwater science and engineering by the public and policy makers.

The scientific mediation process depicted in Figure 4 attempts to reach agreement on the merits of the disagreement as opposed to having personal and political biases cloud the “scientific process”. The problems associated with dueling experts is not limited to the policy making process. Large multi-year, multidisciplinary projects undertaken in the academies can also

become similarly entrenched leading to a “schism” among different factions within the research enterprise. While scientific mediation is a process that sounds rather utopian, it is garnering much interest by conflict resolution academics because it moves beyond the tired and overused cliché of “agreeing to disagree” used by “entrenched expert egos.”

6.3 Serious Gaming for Cooperation

Serious games are useful because they provide a structured environment in which learning and research can occur – and they are fun. When it comes to training students and professionals in

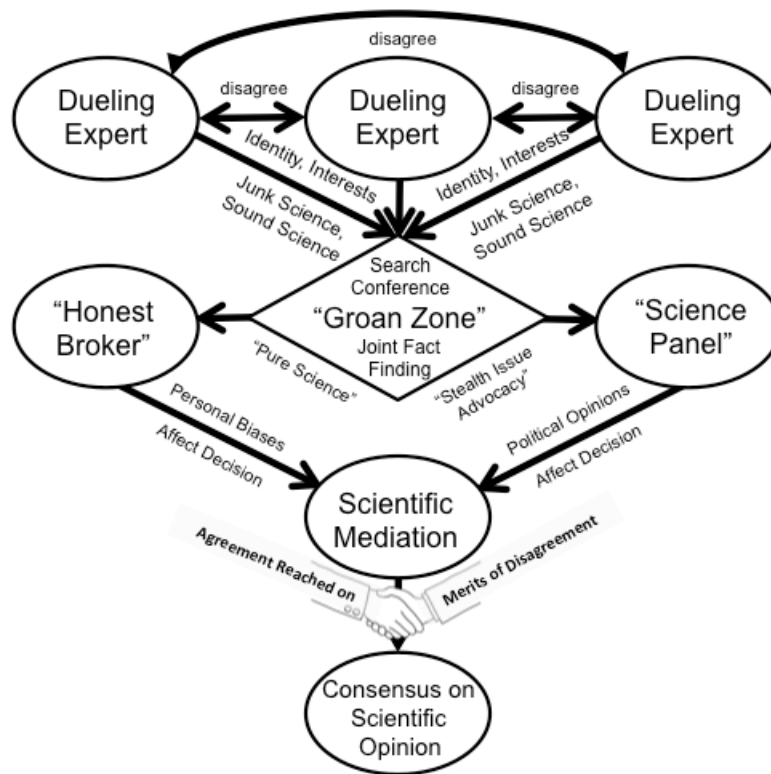


Figure 4: Scientific Mediation Framework (Moore *et al.*, 2015).

water negotiations, everybody likes to play a game (Workman, 2016). In his blog, *The Consensus Building Approach*, Larry Susskind writes “There are various ways games can be used to inform, and even alter, high-stakes policy negotiations...but this only works when the actual negotiators take part in the game in advance of undertaking their own "real life" interactions.”

ADVANCES IN GROUNDWATER GOVERNANCE (book title)

Karen G. Villholth, Jac van der Gun, Elena Lopez-Gunn, Kirstin Conti, and Alberto Garrido (editors) –
In progress, please do not cite (yet)

Serious games introduce the different types of negotiation styles even in situations where language or cultural barriers exist. Many countries are just beginning the organization of alternative dispute resolution systems; computer-based and online games enhance online competency in water negotiations. Collaborative modeling is a form of serious game “playing” with participants developing various groundwater management scenarios.

One of the tried and true approaches to negotiation training is “role plays”. Nearly every academic or professional training program in water negotiations uses role plays. Most focus on surface water allocations, water rights, benefit sharing, how to move water, and the benefits associated with water, across political boundaries.

However, the topics of the groundwater-related simulations are becoming increasingly diverse as groundwater professionals become more involved with both the technical substance of hydrogeology and the process of conflict prevention and resolution. Table 1 lists many different role playing games and their applications to groundwater disputes. The groundwater protection dueling expert role play was developed Jarvis (2014) who works as a groundwater hydrologist that teaches and practices conflict resolution in groundwater and water well construction. It provides a “real-world” situation of the conflicts associated with multiple working hypotheses and the emerging field of scientific mediation. Likewise, the Edwards Aquifer Case was developed by a government scientist and academic collaborative governance practitioner for the complex situation of groundwater as a private property right grounded by the Endangered Species Act.

Board games with “currencies” permit “negotiations” around a table where multiple languages are spoken. *Santiago* is a water allocation board game with farms, fleeting fidelities that fiddles with bribery. The groundwater counterpart to *Santiago* is the *California Water Crisis Game* - a groundwater board game where the winner is the player with the best reputation.

A pioneer in computer games is the *Tragedy of the Groundwater Commons Groundwater Game* developed by the U.N. International Groundwater Resources Assessment Centre (IGRAC). This game is part of IGRAC’s GroFutures - Groundwater futures in Sub-Saharan Africa project. The game uses of a spreadsheet model to analyze well development impacts and economics to

ADVANCES IN GROUNDWATER GOVERNANCE (book title)

Karen G. Villholth, Jac van der Gun, Elena Lopez-Gunn, Kirstin Conti, and Alberto Garrido (editors) –
In progress, please do not cite (yet)

neighboring water users. Isaak (2012) provides an excellent review of the game played by a transdisciplinary group of university students in the US.

7 SUMMARY

This chapter provides an overview of the challenges associated with conflict and cooperation over groundwater and aquifers. Conflicts over groundwater and aquifers are markedly different than conflicts over surface water resources, in part because of the hidden nature of aquifers, the conceptual models developed by practitioners of popular and formal hydrology, uncertainty and fragmentation of data, data collection, data interpretation, and application of data to address the schizophrenic approaches to managing surface water, groundwater, and seawater at micro, macro, and meso scales. Threats to groundwater quality are more conflictive than disputes over allocations that typify surface water resources. While disputes over interference between surface water rights and groundwater development and groundwater depletion will continue with increases in population and climate change causing a “redistribution” of precipitation, emerging conflictive situations connected to groundwater and aquifers include continued influx of nitrate, groundwater flooding, development of subsea aquifers, and hydrofracking. Cooperation can be enhanced through a transdisciplinary approach to water negotiations, refusing to accept tired clichés such as “agreeing to disagree” uttered by dueling experts through scientific mediation, and embracing the challenge of having fun and learning from each other through serious gaming.

ADVANCES IN GROUNDWATER GOVERNANCE (book title)

Karen G. Villholth, Jac van der Gun, Elena Lopez-Gunn, Kirstin Conti, and Alberto Garrido (editors) –
In progress, please do not cite (yet)

Table 1: List of Serious Groundwater Games

Game	Situation	Reference
Water on the West Bank Role Play	Water well siting, aquifer depletion	Harvard Program on Negotiation (1988)
Managing Groundwater Beneath the Pablo-Burford Border Role Play	Agriculture water quantity and quality	Harvard Program on Negotiation (1996)
Santiago Board Game	Diversion of spring water to canals for plantations	AMIGO Spiel http://www.amigo-spiele.de/
International Groundwater Negotiation Role Play	Source of recharge and hydraulic connection to a transboundary water resources	Paisley (2008)
Tragedy of the Groundwater Commons Computer Assisted Role Play	Hydrologic “capture” analysis and economics of pumping wells	IGRAC http://www.un-igrac.org/downloads
Groundwater Protection Dueling Expert Role Play	Wellhead protection and aquifer protection boundaries	Jarvis (2014)
California Water Crisis Board Game	Groundwater use and depletion in California for agriculture, ecosystems, and urban growth	Firstcultural Games https://www.thegamecrafter.com/games/california-water-crisis
The Edwards Aquifer Case Role Play	Groundwater, common law rule of capture, Endangered Species Act, and role of science	Zerrenner & Gulley (2016)

ADVANCES IN GROUNDWATER GOVERNANCE (book title)

Karen G. Villholth, Jac van der Gun, Elena Lopez-Gunn, Kirstin Conti, and Alberto Garrido (editors) –
In progress, please do not cite (yet)

REFERENCES

- Aladjem, D. (2015) Into the trenches: an early assessment of California's new groundwater legislation. *The Water Report*, 135, 20-26.
- Benjamin, R. (2015) Game playing in negotiation: Part 2, an inventory of strategies and devices. *mediate.com* [Online] Available from: <http://www.mediate.com/articles/BenjaminMachiavelli2.cfm> [Accessed 13th August 2016].
- Daniels, S.E. & Walker, G.B. (2012) Lessons from the trenches: Twenty years of using systems thinking in natural resource conflict situations, systems research and behavioral science. *Systems Research and Behavioral Science*, 29, 104–115.
- Delgado, P.A.T. (2013) *Collaborative Assessment and Management of Transboundary Aquifers In North America*. Master of Science in Environmental Science Thesis [Online], Corvallis, Oregon State University. <http://hdl.handle.net/1957/45046> [Accessed 13th August 2016].
- Delli Priscoli, J. & Wolf, A. (2009) *Managing and Transforming Water Conflicts*. New York, Cambridge University Press.
- Earth Security Group (2016) *Earth Security Index: Business Diplomacy for Sustainable Development*, [Online] earthsecuritygroup.com/esi2016 [Accessed 13th August 2016].
- Isaak, M.T. (2012) Tragedy of the Commons Game. *Arizona Water Resource Newsletter*. Winter 2012. [Online] Available from: <https://wrrc.arizona.edu/awr/w12/commonsgame> [Accessed 13th August 2016].
- Islam, S. & Susskind, L.E. (2013) *Water Diplomacy: A Negotiated Approach to Managing Complex Water Networks*. New York, NY, RFF Press, Routledge.
- Jarvis, T. & Wolf, A. (2010) Managing Water Negotiations: Theory and approaches to water resources conflict and cooperation. In: Earle, A., Jägerskog, A. & Öjendal, J. (eds.) *Transboundary Water Management: From Principles to Practice*. London, Earthscan. pp. 125–154.
- Jarvis, W.T. (2014) *Contesting Hidden Waters: Conflict Resolution for Groundwater and Aquifers*. London, Earthscan.
- Kemper, J.B. (2016) *Groundwater Flooding and Guerilla Trenches: a Participatory Approach for Flood Control*. Master of Sciences in Water Resources Engineering Thesis [Online] Corvallis, Oregon State University. <http://ir.library.oregonstate.edu/xmlui/handle/1957/59209> [Accessed 13th August 2016].
- Kurki, V.O. (2016) *Negotiating Groundwater Governance: Lessons from Contentious Aquifer Recharge Projects*. Ph.D. Dissertation [Online] Tampere, Finland. Tampere University of Technology. 1387. [https://tutcris.tut.fi/portal/en/publications/negotiating-groundwater-governance\(a3bde410-fc67-49b2-9d31-c77c3c0d9a13\).html](https://tutcris.tut.fi/portal/en/publications/negotiating-groundwater-governance(a3bde410-fc67-49b2-9d31-c77c3c0d9a13).html) [Accessed 13th August 2016].
- Martin-Nagle, R. (2015) Offshore Aquifers. *The Environmental FORUM*, 32 (3) 26-31.

ADVANCES IN GROUNDWATER GOVERNANCE (book title)

Karen G. Villholth, Jac van der Gun, Elena Lopez-Gunn, Kirstin Conti, and Alberto Garrido (editors) –
In progress, please do not cite (yet)

Moran, T. & Cravens, A. (2015) *California's Sustainable Groundwater Management Act of 2014: Recommendations for Preventing and Resolving Groundwater Conflicts*. [Online] Water in the West, Stanford University.
http://waterinthewest.stanford.edu/sites/default/files/SGMA_RecommendationsforGWConflicts_2.pdf [Accessed 13th August 2016].

Moran, T.A. Cravens, J. Martinez & Szeptycki, L. (2016) *From the Ground Down: Understanding Local Groundwater Data Collection and Sharing Practices in California*. [Online] Water in the West, Stanford University.
<http://waterinthewest.stanford.edu/sites/default/files/GW-DataSurveyReport.pdf> [Accessed 13th August 2016].

Moore, C., Jarvis, T. & Wentworth, A. (2015) Scientific Mediation, *mediate.com*. [Online] Available from: <http://www.mediate.com/articles/JarvisT1.cfm> [Accessed 13th August 2016].

OECD (2015) *Drying Wells, Rising Stakes: Towards Sustainable Agricultural Groundwater Use, OECD Studies on Water*. [Online] Paris OECD Publishing http://www.oecd-ilibrary.org/agriculture-and-food/drying-wells-rising-stakes_9789264238701-en [Accessed 13th August 2016].

Paisley, R. K. (2008) *FAO training manual for international watercourses/river basins including law, negotiation, conflict resolution and simulation training exercises*. [Online] Food Agriculture Organization of the United Nations (FAO). Available from:
http://www.fao.org/nr/water/faonile/fao-manual_negotiationskills-internationalwaterlaw_sep07.pdf [Accessed 13th August 2016].

Post, V.E.A., Groen, J., Kooi, H., Person, M., Ge, S. & Edmunds, W. M. (2013) Offshore fresh groundwater reserves as a global phenomenon. *Nature*. [Online] 504, 71-78. Available from:
<http://www.nature.com/nature/journal/v504/n7478/full/nature12858.html> [Accessed 13th August 2016].

Vinett, M. & Jarvis, T. (2012) Conflicts Associated with Exempt Wells: A Spaghetti Western Water War. *Journal of Contemporary Water Research & Education*. 148, 10-16. Available from:
http://ucowr.org/files/Achieved_Journal_Issues/148/148_3.pdf [Accessed 13th August 2016].

Workman, J. (2016) Games about frontiers: Building skills to negotiate the politics of water. *The Source Magazine*. June 10, 2016 [Online] Available from:
<http://www.thesourcemagazine.org/games-about-frontiers/> [Accessed 13th August 2016].

Zerrenner, A. & Gulley, R. (2016) The Edwards Aquifer. [Online] The Program for the Advancement of Research on Conflict and Collaboration (PARCC), Maxwell School of Citizenship and Public Affairs, Syracuse University,
https://www.maxwell.syr.edu/parcc/eparcc/cases/The_Edwards_Aquifer/ [Accessed 13th August 2016].